A One-Meter X-Band Inflatable Reflectarray Antenna

John Huang and Alfonso Feria

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, USA

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Abstract: A one-meter, X-band, circularly polarized, inflatable microstrip reflectarray has been developed. It has demonstrated the achievement of a surface tolerance of ±1.3 mm, a mass of 1.2 kg, a bandwidth of at least 3%, a peak sidelobe and a peak cross-pol of -18 dB, and a radiation efficiency of 37%. Correctable areas have been identified to improve the radiation efficiency in the future.

Introduction: Inflatable antenna technology is being developed by JPL/NASA to enable the capabilities of low-mass, high packaging efficiency, and low-cost deployment for future spacecraft high-gain antennas. One of the technologies being studied [1] is the inflatable microstrip reflectarray. The conventional inflatable parabolic reflector antenna offers similar advantages with the added capability of wide electrical bandwidth. However, it suffers from the difficulty of maintaining its required curved-parabolic surface, especially over a long period of time, in the space environment. Since the microstrip reflectarray has a flat reflecting surface, it is much easier to maintain its required surface tolerance using an inflatable structure. This is the primary reason, despite its narrower bandwidth characteristic, that the inflatable microstrip reflectarray is being studied. This paper introduces a one-meter X-band inflatable microstrip reflectarray that was recently developed as a breadboard ground demonstration model for future deep space telecommunication application.

Antenna Description: A photograph of the breadboard X-band inflatable microstrip reflectarray with a one-meter diameter aperture and circular polarization is shown in Fig. 1. The antenna consists of three primary components: the one-meter-diameter thin-membrane reflectarray surface, an inflatable feed-strut tripod structure, and a circular inflatable torus that supports the thin-membrane reflectarray surface. Both the feed-strut tripod and the torus are made of inflatable tubes 13 cm in diameter fabricated using 0.25 mm thick urethane coated Kevlar material. For deployment and test purposes, the tubes are pressurized up 5 psi. Because of the possibility that the structure may lose pressure, after initial inflation due to leakage (micrometeorite penetration, manufacturing defects, etc.), the material needs to be rigidized in order to maintain its structural integrity. Several rigidization techniques and materials are being studied for long term space missions. The techniques being considered include hydro-gel based materials, epoxy coated tubes and stretched aluminum structures, among others.

The one-meter reflectarray surface consists of two layers of thin membranes with each layer made of 5 micron thick copper deposited on 0.05 mm thick Kapton membrane (a polyimid material). The copper on the top layer was etched to form approximately one thousand square microstrip patches (each 1.5 cm square) with different-length phase-delay lines attached [2,3,4]. Each patch is dual-linearly polarized with two orthogonal phase delay lines attached as shown in Fig. 2. With the feed circularly polarized, the reflectarray radiates circular polarization. The bottom layer serves as the ground plane and is separated 1.3 mm from the top layer by several hundred small circular foam disk. These foam disks, 7 mm diameter each, are used to maintain a uniform membrane spacing after the deployment of the inflatable structure. It is critical that all microstrip patches have uniform spacing from their ground plane so that they all resonate at the same RF frequency. The two-layer reflectarray membrane surface is supported to maintain its required flatness by the inflated torus tube at 15 circumferential catenary attachment points. The length dimensions (or the tensions) of these attachment points were manually adjusted so that the required planarity of the membrane surface was achieved. The antenna has achieved the required global surface tolerance of less than ± 1.3 mm.

For the deployment mechanism, it has been determined that a roll-up, instead of a folding, mechanism is the best for the multilayer surface. In other words, the one-meter-diameter circular structure, when deflated, is rolled up to form a one-meter-long cylindrical structure with minimum volume. The folding scheme is not desired here because of the creases formed on the relatively thick copper membrane at the fold lines, especially at the multi-fold corners. The feed of the reflectarray is a conical horn made of 0.65-mm-thick aluminum. It is to be supported by a plastic disk at the focal point when the antenna is deployed in space. During ground test, the feed horn is supported separately by a rigid structure so that its weight does not distort the thin-membrane inflatable structure. The complete inflatable antenna structure achieved a mass of 1.2 kg which excludes the mass of the inflation system. With future development, it is believed that the mass of the inflation system can be on the order of 0.5 kg.

RF Test Results: The measured antenna pattern at 8.3 GHz is shown in Fig. 3. The patterns measured from 8.2 GHz to 8.5 GHz are very similar to that at 8.3 GHz. The pattern of Fig. 3 has a 3-dB beamwidth of 2.4 deg., a peak sidelobe level of −18 dB, and a peak cross-pol level at −18 dB. The beamwidth is as expected for a one-meter aperture. The sidelobe level of −18 dB, which is acceptable for the telecom system, is higher than the expected −25 dB level. This higher-than-expected sidelobe level is believed to be the result of feed and strut blockages, imperfect membrane separation, and a certain amount of surface roughness (± 1.3 mm). The higher-than-expected cross-pol level (-18 dB rather than –25 dB) is also believed to be caused by the same reasons. In addition, the scattered field component and the radiation leakage from the phase delay lines that are attached to the patches also contributed to the high cross-pol level. The antenna achieved the expected –1 dB-gain-bandwidth of 250 MHz which is about 3%. The measured antenna peak gain occurred at 8.3 GHz and is 33.7 dB which yields an overall antenna efficiency of 37%, while the expected efficiency should be about 50%. This relatively poor efficiency is primarily due to design and manufacturing inexperiences of this first demonstration model. Imperfect membrane separation (between patches and the ground plane), feed and strut blockages, surface roughness, leakage radiation from phase delay lines are all contributors to the inefficiency. All these errors are correctable and it is believed that future models can be improved to have higher antenna efficiencies.

Conclusion: A one-meter inflatable microstrip reflectarray antenna has been developed to achieve adequate surface flatness and relatively good radiation characteristics with low mass and high packaging efficiency. The relatively poor antenna radiation efficiency of 37% can be improved in the future so that 50% or higher is achieved.

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? Mary Lue - Should this be spelled out? This is not readily familiar to me.

References:

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List of Figures

Figure 1

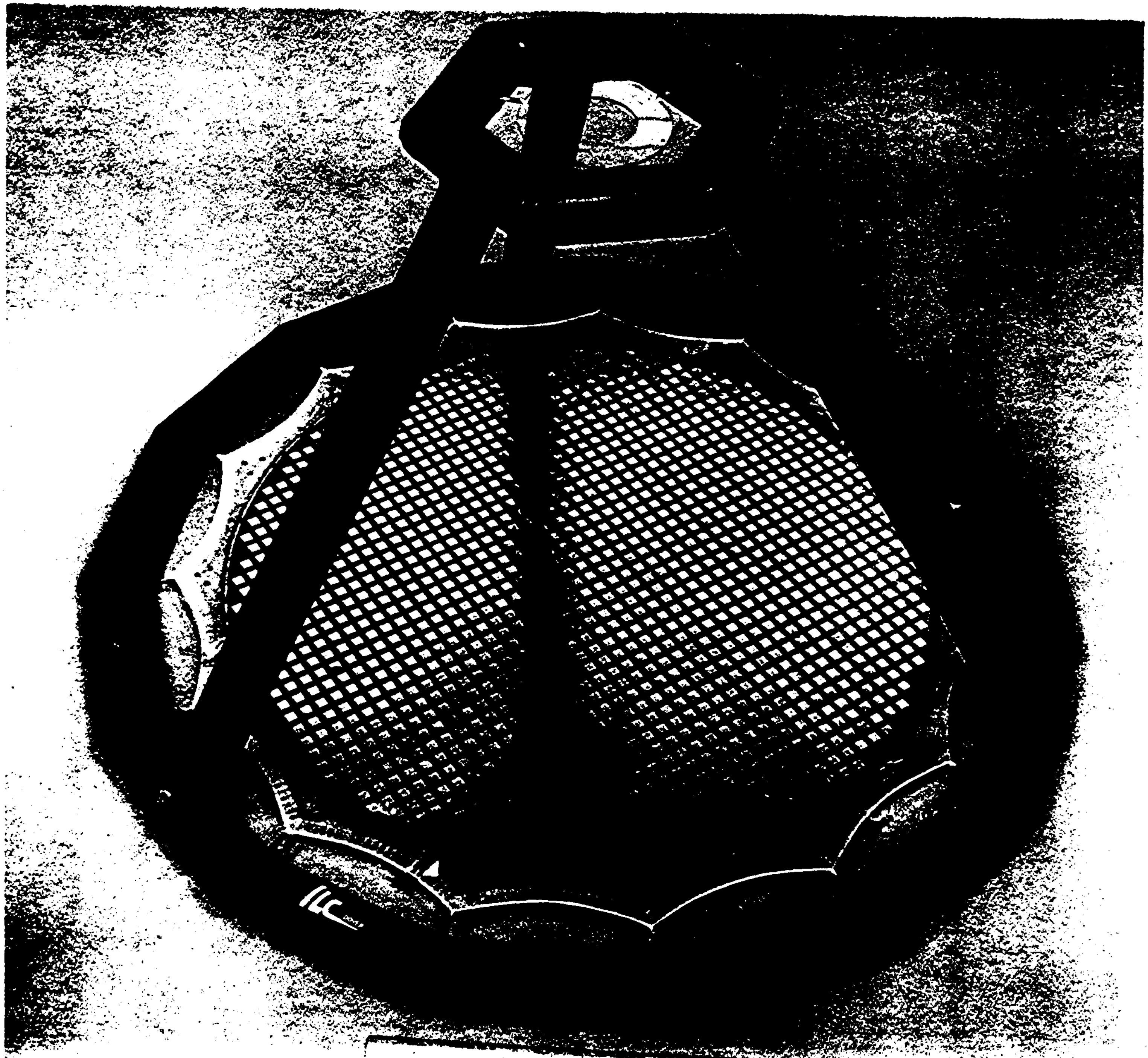


Figure 2

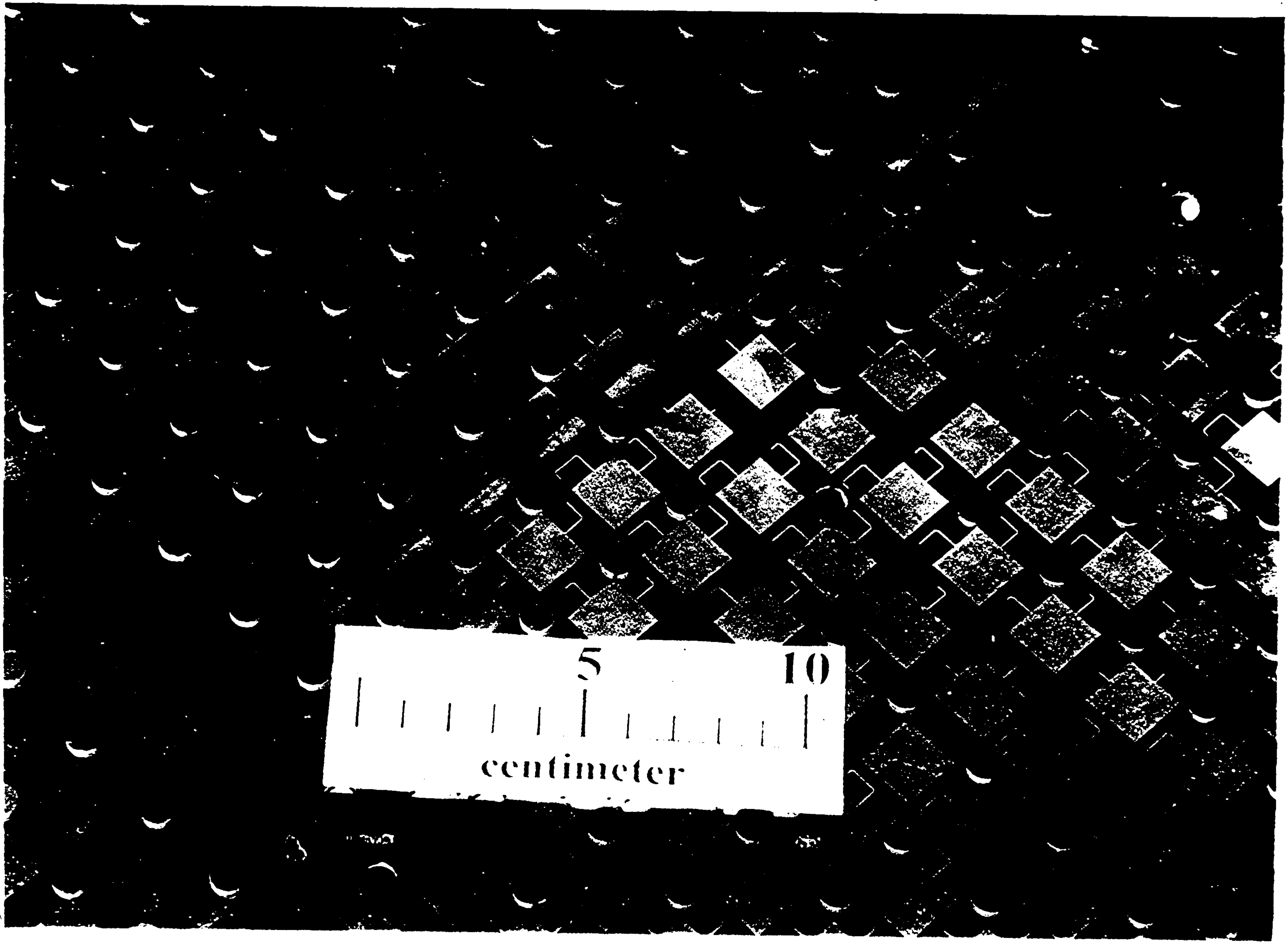
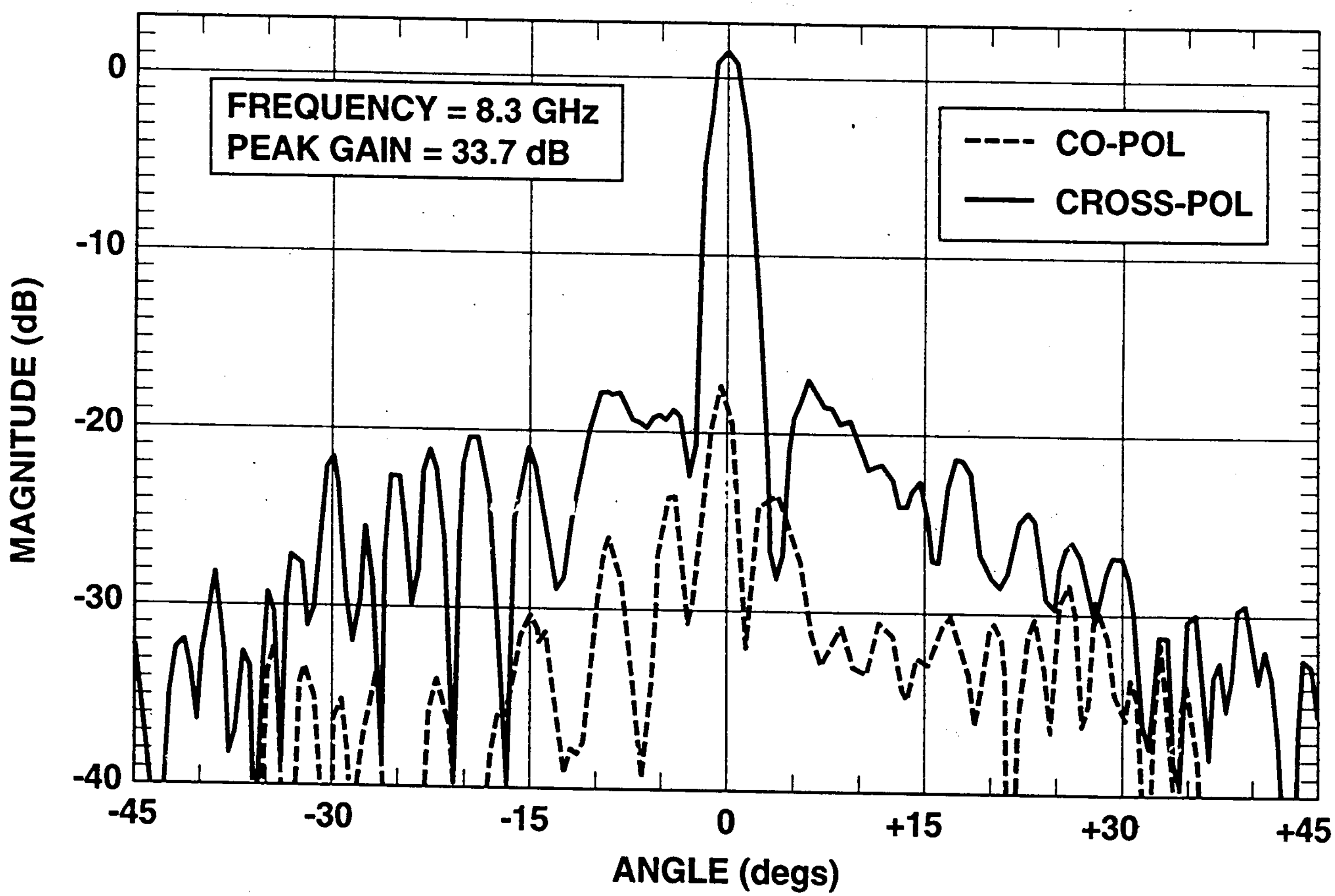


Figure 3



FREQUENCY = 8.3 GHz
PEAK GAIN = 33.7 dB
CO-POL
CROSS-POL
0
-10
-20
-30
-40
MAGNITUDE (dB)
-45
-30
-15
0
+15
+30
+45
ANGLE (degs)